

Research Article

Research on the Interchange Performance of Transportation Hub Based on Yishan Road Station, Shanghai

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Abstract: With the development of rail transit in China, interchange efficiency is more and more important. This study conducted model based research on interchange evaluation based on Yishan Road station in Shanghai, China. Transportation hub interchange evaluation model was established by combing Fuzzy Method and Analytic Hierarchy Process. Calculation result showed that established model can be used to evaluate the interchange performance of Yishan Road station. Based on this model, VISSIM simulation conducted on the interchange performance on Yishan Road station. Results showed that travelling time and speed were not satisfied. Optimized model was then established to order to improve interchange performance. Simulation results showed that significant improvement was observed in travel time and speed, lining-up time and stop frequency, which indicated the usefulness of model on interchange efficiency.

Keywords: Evaluation model, interchange efficiency, simulation, Yishan road station

INTRODUCTION

Urban rail transit is a kind of safe, convenient, punctual and high flow transportation, which is an effective solution to urban traffic jams. Compared with other public transports, urban rail transport has the characteristics as follows: saving land, big transport capacity, 10 times the delivery capacity of highway transportation (Yang *et al.*, 2011a).

China urban rail transport developed rapidly. Total length of rail transit network of China urban planning to construct is to 5000 km, with total investment estimated to be more than 800 billion Yuan. With the rapid development of urbanization, as an important part of China urban public traffic network, the construction of urban rail transport network developed quickly. More than ten cities including Beijing, Shanghai, Guangzhou, Shenzhen, etc., had constructed rail transit lines and there are 25 cities which are included in national planning to construct rail transit network.

As a high capacity, rapid and timeliness transportation, urban rail transportation system is becoming the dominating way of urban public transportation. Interchanging is the most important part of rail transit system. Interchange station is the interchange section of rail system, in which passengers can reach other transportation means. Convenience is the most important factor for the efficiency of rail system. Thus, the transfer system should fulfill the requirement of convenience, comfort and safety.

Among these requirements, most should be based on the smooth transfer between rail transit and other means, to optimize the interchange station. Optimizing the main interchange stations organization has a double benefit: A benefit on the construction costs, indeed by planning the main interchange stations during the feasibility studies of the lines, it is possible to make provisions for the future lines and avoid works on a constructed station, which can be very expensive. A benefit on the transfer time and the accessibility, indeed to optimizing the main interchange stations aim at improving the transfer between the lines but also the access to the stations and therefore the convenience of the station and the whole urban rail network (Yang *et al.*, 2011b).

Among the cities with rapid rail system, Shanghai and Beijing have the most advanced rail transit system. Many researches were conducted in these two cities. He and Liu (2008) used the KLP method to study passengers transfer resistance in interchange hub to improve convenience of the interchange. Zhao (2011) used compute method to match transport capacity. Based on minimal travelling time, the optimum station spacing between bus and urban rail transit was determined. Based on rough set theory and grey clustering model, Zong *et al.* (2011) determined weighting coefficient between the urban rail and metro and put this method in actual case. Mu and Mi (2010) establishes an evaluation index system of urban rail transit to evaluate the transfer efficiency of rail

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transport. Based on Beijing Fuxingmen Interchange Station, Wang *et al.* (2007) proposed an evaluation system from the adaptability of infrastructure capability, transfer security and transfer convenience. Bai *et al.* (2006) established a multi-objective fuzzy synthetics evaluation of the interchange station layout, which consist of 9 factors on the part of network development, improvement of passenger trip conditions and operation results. Zhu (2004) discussed the design and implement of several transfer hubs in Shanghai urban rail transit network, based on the experiences and lessons in the transfer station construction of Shanghai urban rail transit.

Researches on the transfer system of rail transit were mainly on the evaluation of transfer between rail transit and other means. Little emphasis was put on the transfer system of rail transportation hub. To have a better rail and other means transfer, the arrangement of rail transit system is quite important. Many factors should be included, such as passenger flow, land utilization around station, consistence with the close environment, coordination with transportation network and strategy, inter-adaptation with future rail systems, rational connection with other means and so on. The arrangement of station is a systematic work, which should integrate the space, timing and economy.

Yishan Road station is one of the comprehensive interchange and transit center, which consists of interchange station for subway line 3, 4 and 9 and also 8 bus lines. Line 9 is one of the important line connecting urban and suburb area, which is getting more and more important. In the 27 thousand m² main building, it includes one subway transit center, 4 bus interchange stations which connect more than 8 bus lines directly and also more than 10 thousand m² parking area (Shanghai Metro, <http://www.shmetro.com>). Based on the situation of Yishan Road station, research on interchange strategy on interchanging hub was conducted to determine the best solution for interchange strategy.

EVALUATION MODEL FOR INTERCHANGE

Establish of evaluation model for interchange should follow this sequence. First, traffic network initialization. In order to calculate traffic flow for each transportation mode, the traffic network must be initialized first. Second, traffic service level enactment. Factors affecting traffic service level includes time (speed), ticket price, operating frequency, direct cost, walking time, transit time and waiting time, which are used as criterion for transportation mode selection. Furthermore, crowding and comfort-ability should also be taken into consideration. Third, transit share for transport modes. In this study, evaluation model was established based on Fuzzy evaluation and Analytic Hierarchy Process (AHP), as followed.

Establish evaluation index group: Evaluation index group should include all the main factors affect interchange efficiency, which are interchange time, average interchange distance, average interchange facility area, transporting load capacity, management and control. It can be shown as Eq. (1):

$$U = \{ \mu_1, \mu_2, \dots, \mu_n \} \quad (1)$$

This index group can be divided into two levels. First level is:

$$U = \{ u_1, u_2, u_3, u_4, u_5 \} \quad (2)$$

In which,

- u₁ = Average interchange time
- u₂ = Average interchange distance
- u₃ = Average interchange facility area
- u₄ = Transporting load capacity
- u₅ = Management and control

The second level is shown in Eq. (3):

$$u_k = \{ u_{k1}, u_{k2}, \dots, u_{kq} \}$$

$$u_1 = \{ u_{11}, u_{12}, u_{13} \}$$

$$u_2 = \{ u_{21}, u_{22} \}$$

$$u_3 = \{ u_{31}, u_{32} \}$$

$$u_4 = \{ u_{41}, u_{42} \}$$

$$u_5 = \{ u_{51}, u_{52} \} \quad (3)$$

where,

- u₁₁ = Interchange walking time
- u₁₂ = Line waiting time
- u₁₃ = Interchange waiting time
- u₂₁ = Distance between stations
- u₂₂ = Interchange route
- u₃₁ = Platform area
- u₃₂ = Passenger flow
- u₄₁ = Transportation capacity
- u₄₂ = Stop frequency
- u₅₁ = Facility management
- u₅₂ = Management method

Identify index weight: Based on the importance of each index, the index weight was determined by using AHP method, shown in Eq. (4):

Table 1: Average corresponding index value of verdict matrix

Order	1	3	4	5	6	7	8	9	10
RI	0	0.52	0.39	1.12	1.26	1.36	1.41	1.46	1.49

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \quad (4)$$

Based on this matrix, corresponding verifying was induced by using Eq. (5):

$$CR = \frac{CI}{RI} = \frac{\lambda_{\max} - n}{n - 1} / RI \quad (5)$$

where,

λ_{\max} = Maximum eigenvalue of matrix

n = Order of matrix

RI = Average corresponding index related to order, shown in Table 1

Generally, if CR is less than 0.1, verdict matrix is acceptable. Otherwise, matrix has to be redone.

Then, weight for each index can be determined by calculating the eigenvector corresponding to maximum eigenvalue in each level matrix.

Establish evaluation grade: A grade group was established to evaluate interchange situation in transition hub. It can be defined as Eq. (6):

$$V = \{V_1, V_2, \dots, V_n\} \quad (6)$$

where, V_j ($j = 1, 2, \dots, n$) represents the corresponding evaluation result of j index. Based on the feature of Yishan Road station, n was defined to 3. Thus the evaluation group can be defined as:

$$V = (\text{Disqualification, qualification, excellent}) \quad (7)$$

In which value limit for each index was 0-20, 20-40, 40-60, respectively.

Establish evaluation matrix based on fuzzy method: The evaluation matrix was established based on Fuzzy method:

$$R_{ij} = \begin{pmatrix} r_{i1} & \dots & r_{in} \\ \vdots & \ddots & \vdots \\ r_{s1} & \dots & r_{sn} \end{pmatrix} \quad (8)$$

where, r_{mj} ($m = 1, 2, \dots, s; j = 1, 2, \dots, n$) represents the degree of membership of index u_{kim} to the j level evaluation V_j .

Based on the relation between index and evaluation, r_{mj} can be determined by following linear function:

$$r_{mj} = \begin{cases} y_{i1}(x) = \begin{cases} 1 & x < a_{i1} \\ x - a_{i1} / a_{i2} - a_{i1} & a_{i1} \leq x < a_{i2} \\ 0 & x \geq a_{i2} \end{cases} \\ y_{ij}(x) = \begin{cases} 0 & x < a_{ij-2} \\ x - a_{ij-2} / a_{ij-1} - a_{ij-2} & a_{ij-2} < x < a_{ij-1} \\ 1 & a_{ij-1} \leq x < a_{ij} \\ x - a_{ij} / a_{ij+1} - a_{ij} & a_{ij} \leq x < a_{ij+1} \end{cases} \\ y_{in}(x) = \begin{cases} 1 & x < a_{in-1} \\ x - a_{in-1} / a_{in} - a_{in-1} & a_{in-1} \leq x < a_{in} \\ 0 & x \geq a_{in} \end{cases} \end{cases} \quad (9)$$

where,

$a_{i1}, a_{i2}, \dots, a_{in}$: The limit value of interchange efficiency index

y : Membership function

x : Index value

Combined evaluation by fuzzy method: The evaluation matrix was established based on Fuzzy method:

$$B = A \otimes R \quad (10)$$

where,

A = Weight vector

R = Belonging vector

\otimes = General Fuzzy combined operation

Fuzzy matrix calculation was conducted for the verdict matrix R_{ki} of second level index u_{ki} . Membership vector B_{ki} ($i = 1, 2, \dots, q$) in grade group V can be obtained for index u_{ki} :

$$B_{ki} = A_{ki} \otimes R_{ki} = (b_{k11}, b_{k12}, \dots, b_{k1n}) = \begin{pmatrix} b_{k11} & \dots & b_{k1n} \\ \vdots & \ddots & \vdots \\ b_{kq1} & \dots & b_{kqn} \end{pmatrix} \quad (11)$$

Then, matrix calculation was done on first level index u_k , to get the membership vector B_k :

$$B_k = A_k \otimes R_k = (b_{k1}, b_{k2}, \dots, b_{kn}) = \begin{pmatrix} b_{k1} & \dots & b_{kn} \\ \vdots & \ddots & \vdots \\ b_{q1} & \dots & b_{qn} \end{pmatrix} \quad (12)$$

Based on those, fuzzy matrix calculation can be done to get the membership vector B of very first level index u :

$$B = A \otimes R = (b_1, b_2, \dots, b_n) \quad (13)$$

Thus, the obtained evaluation is the maximum value.

Model application in Yishan road station: This model was then used on Yishan Road station to verify. Based on the model, the maximum eigenvalue can be calculated through Eq. (14):

$$\lambda_{\max} = \frac{1}{n} \left[\frac{\sum_{j=1}^n a_{1j}w_j}{w_1} + \frac{\sum_{j=1}^n a_{2j}w_j}{w_2} + \dots + \frac{\sum_{j=1}^n a_{nj}w_j}{w_n} \right] \quad (14)$$

The λ_{\max} is 5.42.

Accordingly, the corresponding verifying index CR can be obtained by Eq. (5). As $CR = 0.094 < 1$, this model matrix can be used for interchange evaluation.

Interchange simulation based on VISSIM: VISSIM is the leading microscopic simulation program for multi-modal traffic flow modeling. With its unique high level of detail it accurately simulates urban and highway traffic, including cyclists and motorized vehicles. It is possible to realistically simulate interactions between pedestrian and vehicle flows. You can now run analyses that encompass both types of traffic, as well as analyses specific to pedestrians.

Based on the feature of passenger flow and lines, line and passenger walking model were established based on VISSIM software. Simulation then was conducted to imitate passenger interchange characteristics.

Line model: Line is the primary element of VISSIM transportation network. Network formed by multi-lines can be easily defined its elements in any position. Based on the practical feature of Yishan Road station, line model was established, shown in Fig. 1.

SIMULATION RESULTS

Travelling time: Average travelling time represented the time period for vehicle went through the testing area. A start point and ending point were needed. Figure 2 was the travelling time simulation sketch arrangement. Red line was starting line and green lines were ending line. 1# passenger way was passenger way between Line 9 and 4 with 244 m in length, 2# represent passenger way between Line 9 and 3 with 244 m in length.

Simulation results showed that travelling time for 1# and 2# passenger ways were 214 and 110 sec, respectively. Due to their different distance, average travel speed for 1# and 2# were 1.14 and 1.24 m/sec.

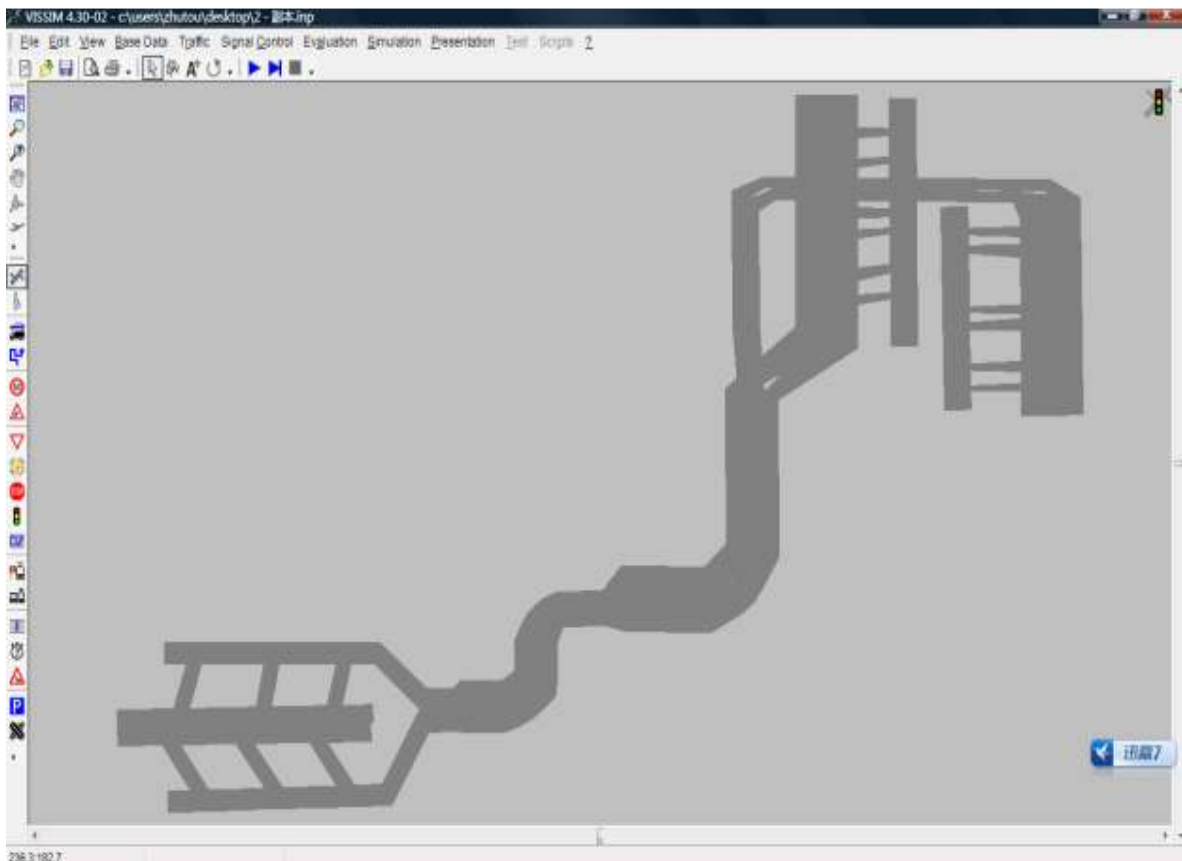


Fig. 1: Line model network of Yishan road station

Table 2: Lining-up length and stop frequency on initial arrangement

Time/s	Queue 1			Queue 2			Queue 3			Queue 4		
	Avg./m	Max./m	Stop	Avg./m	Max./m	Stop	Avg./m	Max./m	Stop	Avg./m	Max./m	Stop
200	0	0	0	0	0	0	0	0	0	0	0	0
400	1	17	38	0	0	0	0	11	3	0	7	3
600	5	27	80	0	5	1	1	13	17	1	15	31
800	4	23	66	0	5	1	1	9	5	1	10	23
1000	3	33	64	0	4	1	1	10	13	1	18	30
1200	3	23	71	0	5	0	3	16	42	1	8	24
1400	2	17	55	0	5	1	1	11	16	1	11	18
1600	3	22	64	0	5	2	1	12	24	1	13	24
1800	3	18	59	0	5	1	1	16	13	1	10	27
2000	3	18	59	0	5	1	1	16	13	1	10	27

Avg.: Average lining-up length, m; Max.: Maximum lining-up length, m

Table 3: Lining-up length and stop frequency on adjust arrangement

Time/s	Queue 1			Queue 2			Queue 3			Queue 4		
	Avg./m	Max./m	Stop	Avg./m	Max./m	Stop	Avg./m	Max./m	Stop	Avg./m	Max./m	Stop
200	0	0	0	0	0	0	0	0	0	0	0	0
400	2	15	40	0	0	0	0	8	6	0	0	0
600	4	20	81	0	5	3	1	11	14	0	0	0
800	3	15	51	0	5	3	1	13	15	0	0	0
1000	3	18	59	0	5	3	1	10	19	0	0	0
1200	4	22	90	0	5	2	1	9	18	0	0	0
1400	2	17	60	0	5	2	1	14	15	0	0	0
1600	5	25	91	0	5	4	1	10	10	0	0	0
1800	3	18	56	0	5	4	1	9	10	0	0	0
2000	3	18	56	0	5	4	1	9	9	0	0	0

Avg.: Average lining-up length, m; Max.: Maximum lining-up length, m

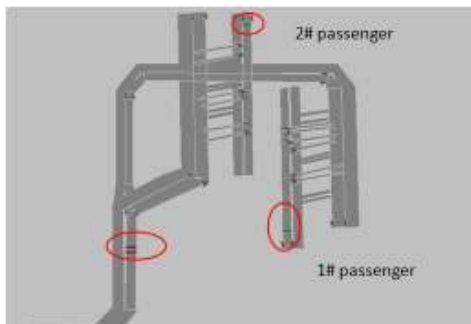


Fig. 2: Travelling time sketch arrangement

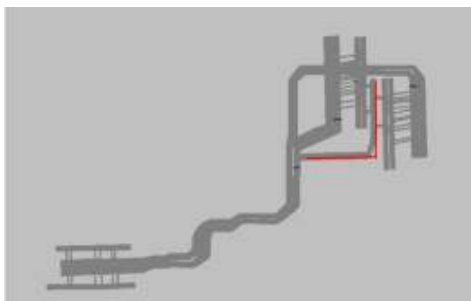


Fig. 3: Adjust line model network with one new line

Travel delay time for 1# was 10 sec, which indicated that actual travel time was 10 sec more than ideal time. Average stop time was 0.6. For 2# passenger way, travel delay time was 2 sec, with 0.6 stop/person.

Lining-up length: VISSIM can provide output of average and maximum lining-up length and stop frequency. Table 2 showed the lining-up length and stop frequency on current arrangement.

Adjust model and simulation:

Adjust model: Due to the heavy passenger flow in Yishan Road station, one new line was added to redistribute passenger flow, to increase interchange efficiency, as shown in Fig. 3 red line. Simulation results showed that this arrangement can improve interchange in Yishan Road station.

Travelling time: Due to the added line, travelling time reduced significantly in 1# passenger way. 1# passenger way travelling time reduced to 105 sec, with average travel speed 1.36 m/sec. For 2# passenger way, travelling time slightly reduced to 95 sec and travel speed increased to 1.36 m/sec.

Obvious travel delay reduced was observed due to the adjust line. For 1# passenger way, delay time reduced to 0.3 sec and stop frequency reduced to 0.1, while for 2# passenger way, travel time delay was 2 sec and stop frequency was 0.3.

Lining-up length: Table 3 showed the lining-up length and stop frequency on the adjust arrangement. Compared with Table 2, adjust arrangement improved interchange efficiency by reducing lining-up length and stop frequency.

CONCLUSION

Interchange efficiency is more and more important due to the development of rail transit in China. Based on the feature of interchange activity, the transportation hub interchange efficiency evaluation model was established by combining Fuzzy Method and analytic hierarchy process. The evaluation matrix was applied to Yishan Road station. Calculation results showed that this model can be used to evaluate interchange efficiency on Yishan Road station. Based on this model, VISSIM simulation was conducted on the interchange performance on Yishan Road station. Results showed that travelling time and speed were not satisfied. Adjusted model was applied. Significant improvement was observed in travel time and speed, lining-up time and stop frequency, which indicated the usefulness of model on interchange efficiency.

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